DOE/OE Transmission Reliability Program

Oscillation Monitoring System

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CERTS

CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

WASHINGTON STATE UNIVERSITY

WSU Research Objectives

- **Oscillation Monitoring System for large power systems**
- **Monitoring hundreds of PMUs simultaneously**
- **System modes are changing – adaptive engines**
- **Interactions with power electronics**
- **Damping Monitor Engine – ambient data analysis**
- **Event Analysis Engine – detection and analysis of ringdowns and oscillations**
- **Real-time engines and off-line engines**

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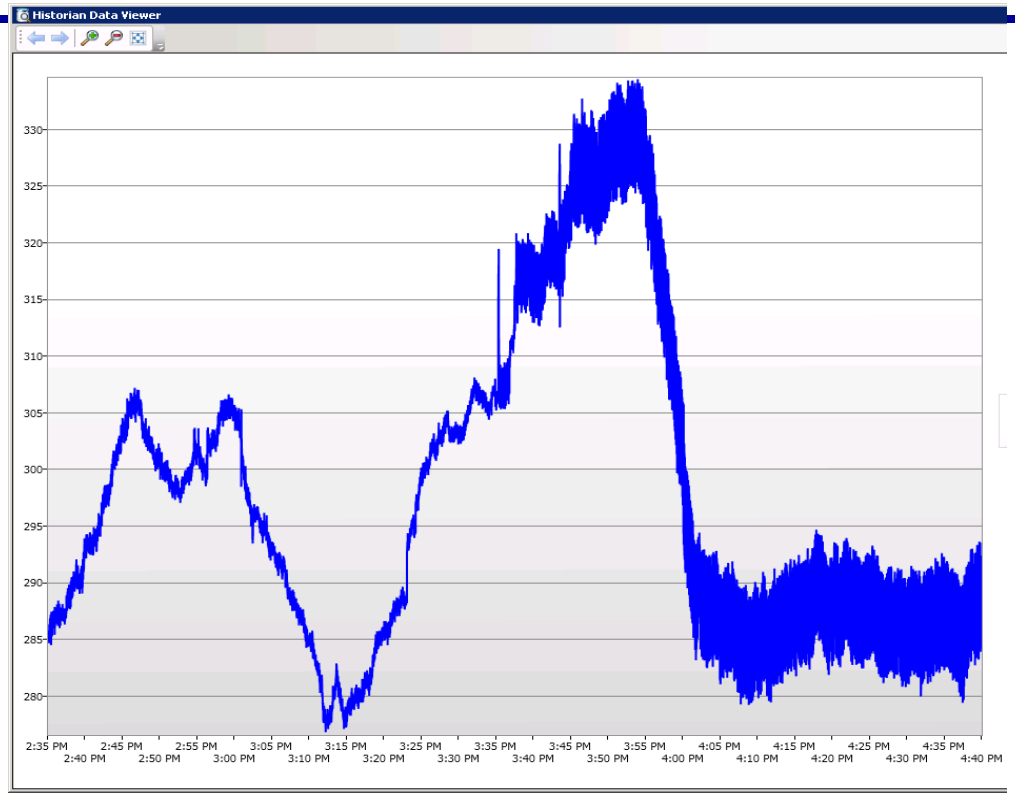
Key Accomplishments

- New algorithms developed for handling of large number of PMU measurements
  - Damping Monitor: DFDO, FFDD, RFDD, DFDD, RASSI, DRSSI
  - Event Analysis: MFRA, METRA
- FFDD implemented at Entergy; 5 Hz oscillations analyzed.
- Source of WECC 0.37 Hz low damping alarms identified to be forced oscillations from a hydro plant in Idaho

Complementary Engines

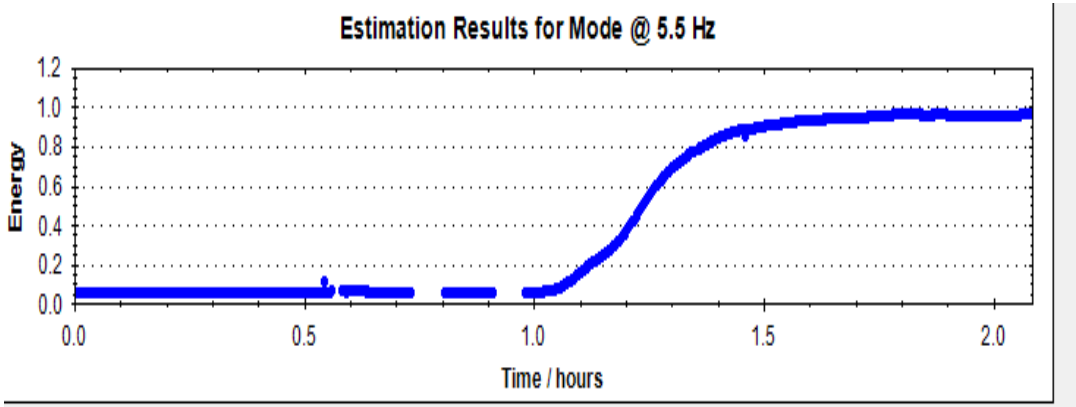
- Event Analysis Engine (EAE)
  - Multiple algorithms
  - Prony, Matrix Pencil, HTLS, ERA, MFRA, and METRA.
  - Aimed at events resulting in sudden changes in damping
- Damping Monitor Engine (DME)
  - Ambient noise based. Continuous. Provides early warning on poorly damped modes.
  - Several algorithms
  - Frequency Domain Decomposition (FDD), DFDO, Recursive Adaptive Stochastic Subspace Identification (RASSI), DFDD, RFDD, and DRSSI

Entergy 5.5 Hz oscillations



Actual Current Magnitude seen in PMU

(From openHistorian)



OMS FDD 5 Hz mode energy level captures the change.

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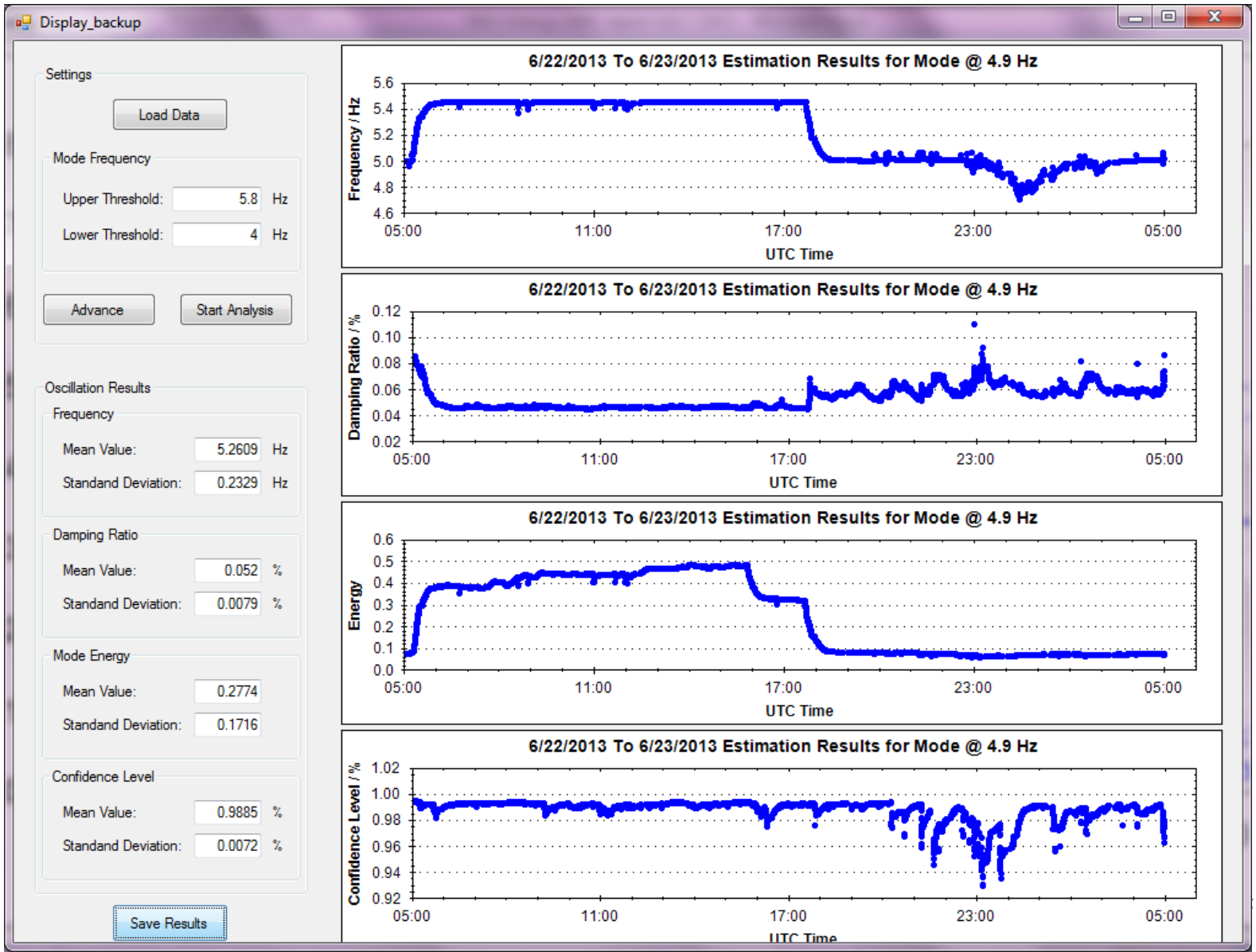
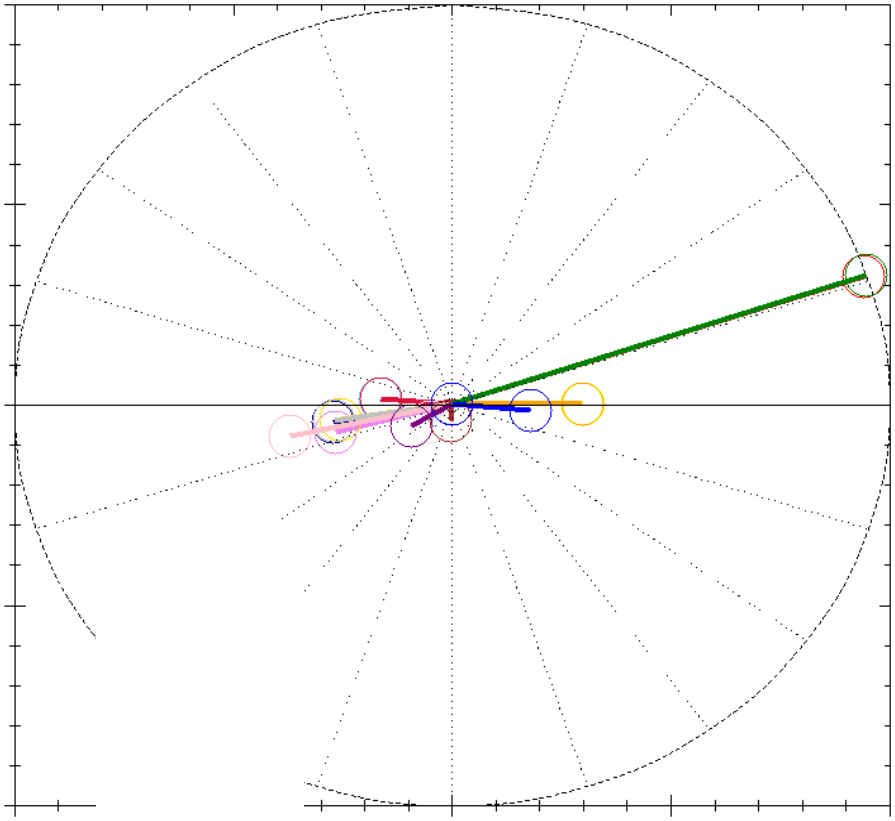
Entergy 5 Hz oscillations

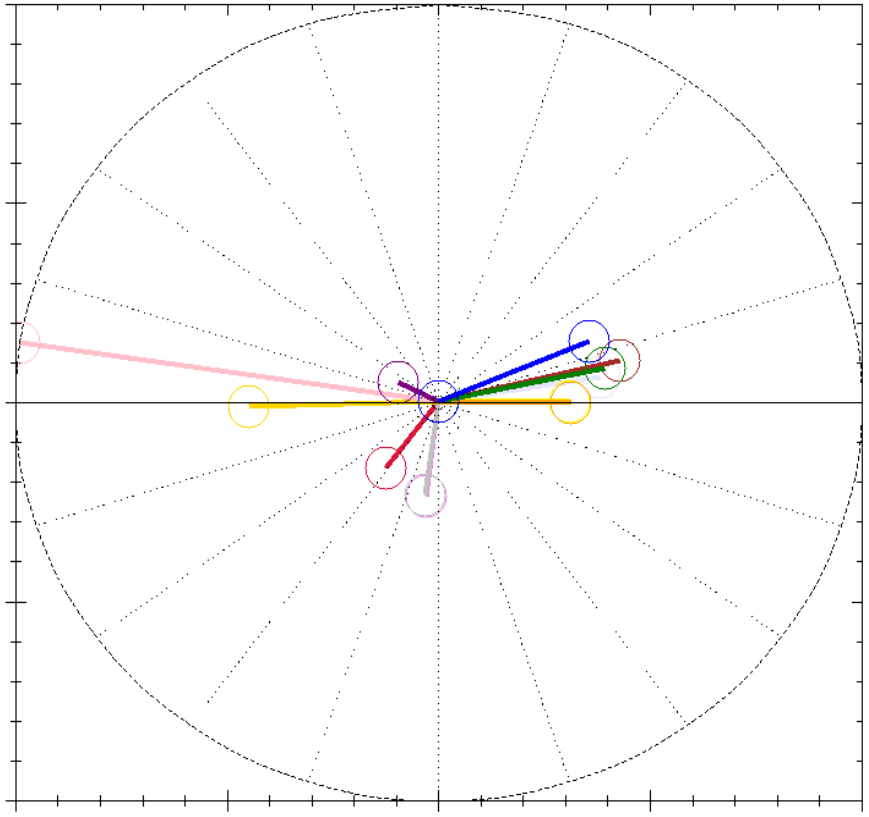


Mode frequency changes during some days

Oscillations from different sources



5.45 Hz mode shape



5 Hz mode shape

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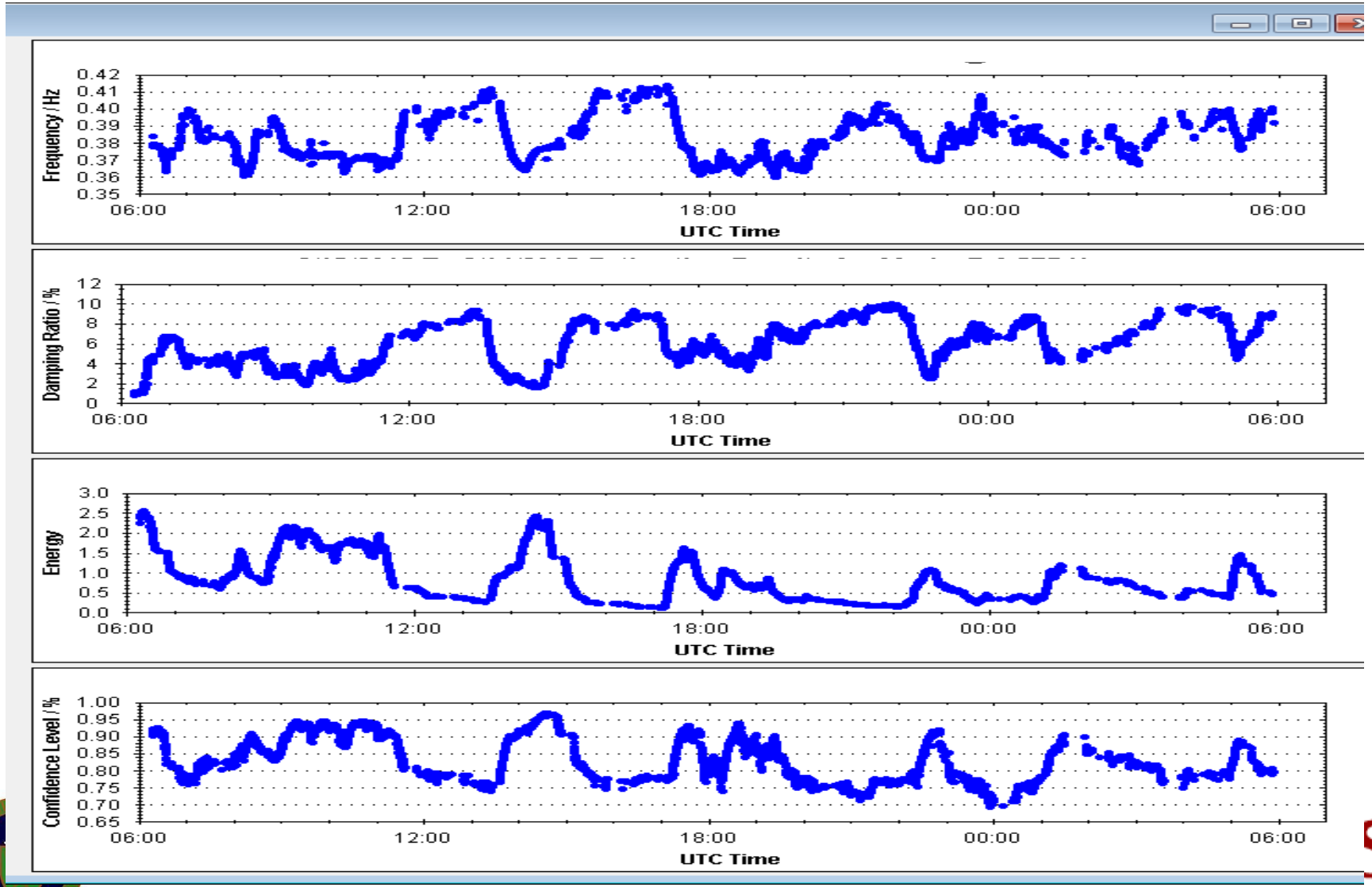
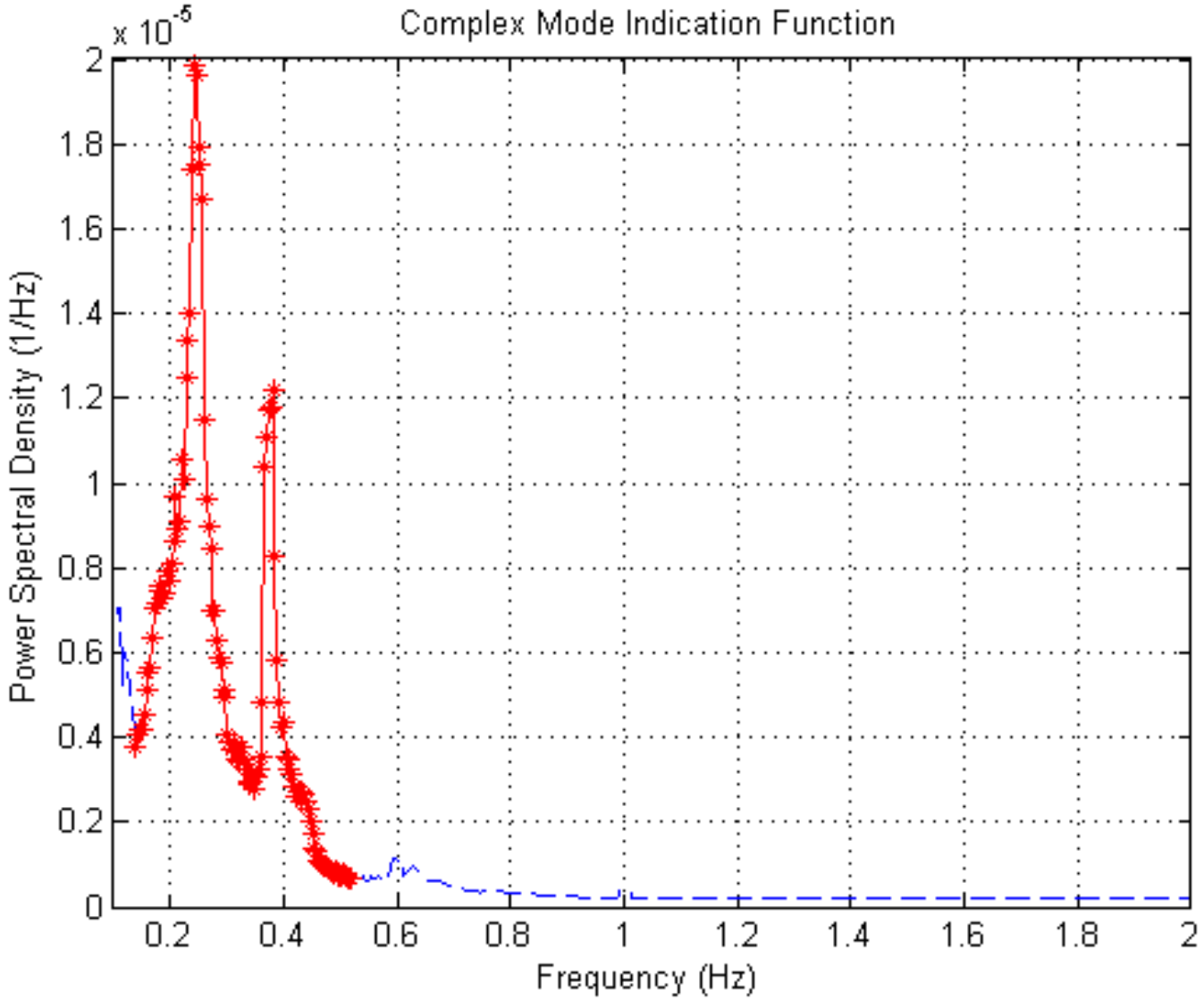
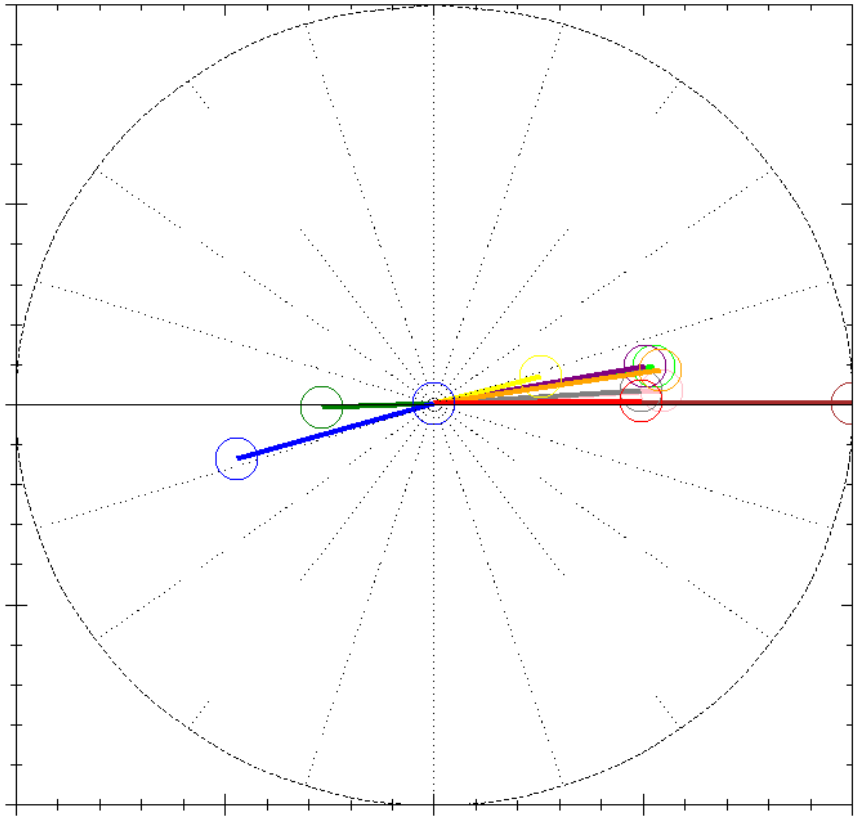
0.38 Hz WECC mode (poorly damped)



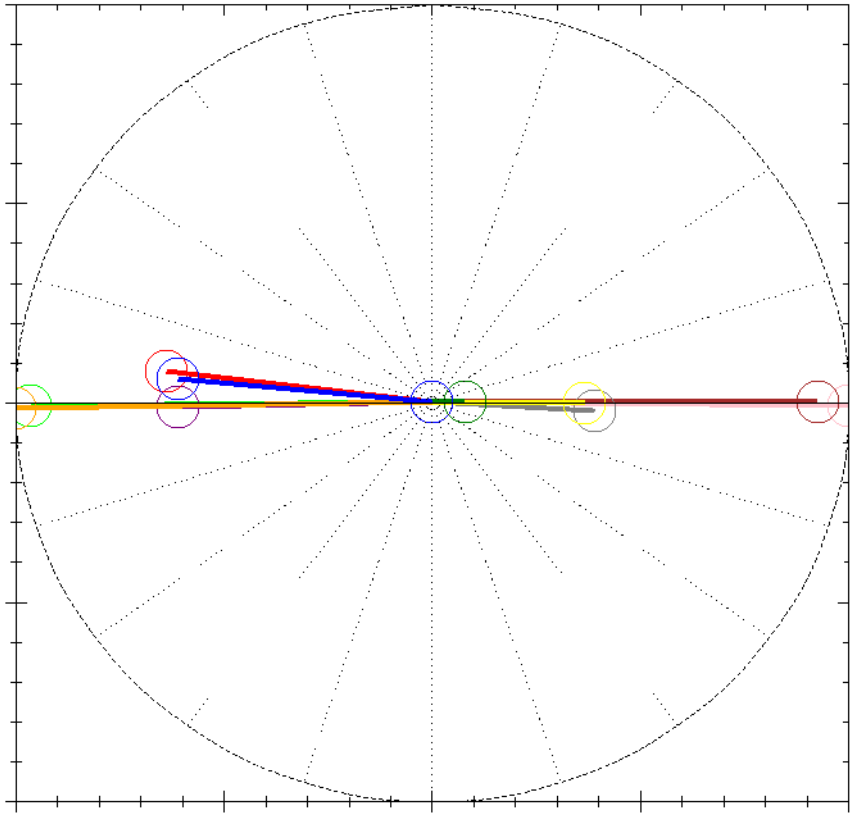
June 13th PSD Singular Values from WECC data



Mode Shapes on June 13, 2013

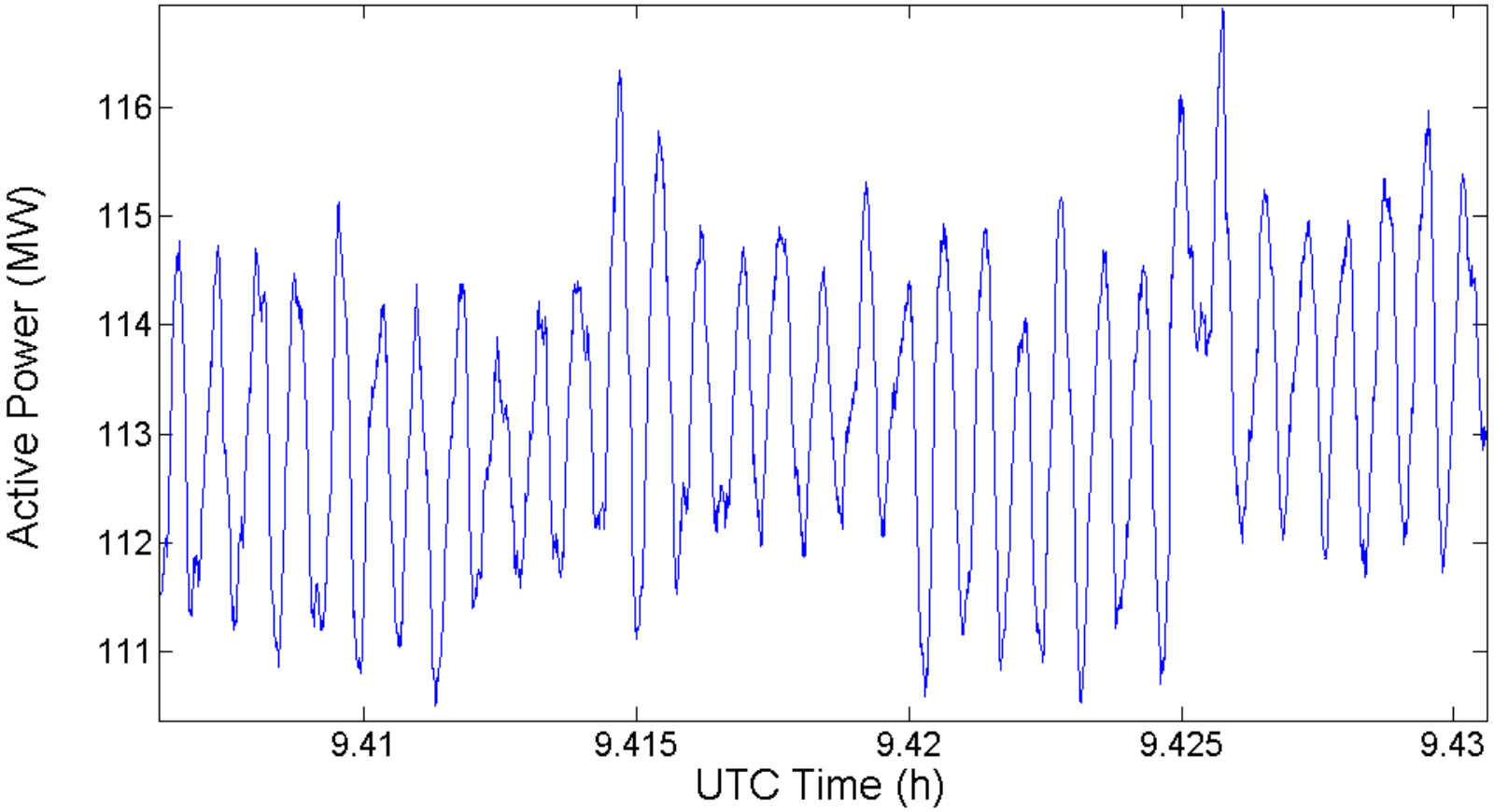


0.37 Hz at
Near Zero Damping Ratio
(7.30 am to 8.00 am)



0.4 Hz at
Near 8% Damping Ratio
(10 am to 11 am)

June 13th 0.37 Hz oscillations at Generator



Generator MW Oscillations

- Hydro operated in rough zone when wind power output high.
- Vortex effect in Francis turbine when water flow level is low
- Air compressor to keep oscillations low to nil
- **5 to 25 MW oscillations observed at 0.37 Hz**
- Tricky for ambient mode monitoring engines
- Mode shape analysis critical
- Multi-dimensional analysis crucial

Forced Oscillations from Hydro

- Summer 2013 24 hour data: 0.37 Hz oscillations observed for several hours. Confirmed to be forced oscillations.
- Another 0.5 Hz oscillation also observed. Source points to hydro unit as well. Forced oscillations?
- Routine phenomenon in hydro units (Francis) when units come in and go out of system
- Detection? Impact on nearby system modes?
- Resonance possible when system mode poorly damped and close. Resonance observed in model simulations. Research and Algorithms at WSU.

Publications

- DFDO, IEEE Trans. Power Systems, May 2013
- RASSI, IEEE Trans. Power Systems, January 2014
- MFRA, IEEE Trans. Power Systems, March 2014
- METRA, Proc. HICSS, January 2014
- PMU applications, Springer-Verlag, M. Kezunovic, S. Meliopolous, V. Venkatasubramanian and V. Vittal, in print.

Technical Objectives in FY14

- **Damping Monitor Engine and Event Analysis Engine**
  - Design of **off-line** engine (Stage 3)
    - Code development, Testing, Training
    - Deliverables: Beta Engines and Training Modules for WECC and Entergy

Risk Factors in FY14

- **Event Analysis Engine and Damping Monitor Engine**
  - **PMU data quality**
  - **Computational complexity of algorithms**

Technical Objectives in FY15

- **Damping Monitor Engine and Event Analysis Engine**
  - Real-Time Engine Prototype (Stage 3)
    - Coding, testing, and tuning
    - Deliverables: Beta versions for Entergy/WECC test labs and Training Modules
  - Off-line Versions
    - Continued Development, Testing and Training